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monthly survey by the U. S. National Committee for the International Geophysical Year. Established and part of the National Academy of Sciences, the Committee is responsible for the U. S. International Geophysical Year program in which several hundred American scientists are participating and many public and private institutions are cooperating.

Seismic Studies in the Western Caribbean

This report is based upon material presented at the IGY Symposium of the American Association for the Advancement of Science, December 29-30, 1958, by John W. Antoine of Lamont Geological Observatory, Columbia University.

During and for several years prior to the IGY, oceanographers of the Lamont Geological Observatory made many seismic refraction measurements in the Caribbean Sea. Their aim was to study crustal structure in an island-arc province in order to determine its relationship to ocean-basin and continental structure. Many geologists and geophysicists feel that island arcs represent an intermediate phase in continent growth. Others hold the view that the interior basin of the island arc is a foundered continental mass.

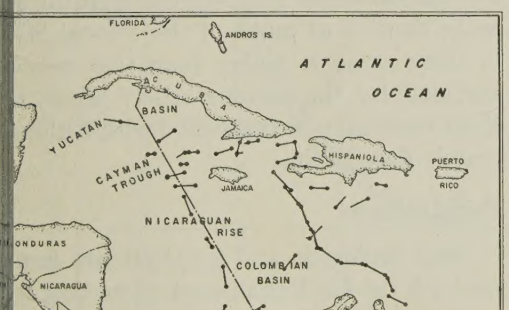


Fig. 1. *Western Caribbean, Showing Locations of Seismic Observations and of Structure Cross Section (A-A').*

The results discussed here are based on 38 seismic profiles, most of them reversed to check accuracy, representing the first submarine structural data in the western Caribbean (see Fig. 1). In general, the crustal thickness varies with water depth, a thin crust being associated with deep waters and a thicker, more complicated crustal section with shallower water. The crust is thinnest in the Cayman Trough, where only .5 km of sediment and 3.2 km of crustal rocks were found. In some of the shallower areas, the thickness of the crust was so great that its base could not be reached with the equipment used.

Analysis of Cross Section

Location: Figure 2 is a cross section through the crust from the Yucatan Basin south-easterly across the Cayman Ridge, the Cayman Trough, the Nicaraguan Rise, and the Colombian Basin to the Continental Slope off Cape Augusta, Colombia. The average water depth in the Yucatan Basin and in the Colombian Basin is about 4 km, while in the Cayman Trough it is about 5 km, deepening to almost 7 km in the Bartlett Deep. The section crosses the Nicaraguan Rise in a saddle between Rosalind Bank, on the west, and Pedro Bank, on the east. The average depth of water along this part of the Rise is about 1 km. The Cayman Ridge was crossed between Grand Cayman

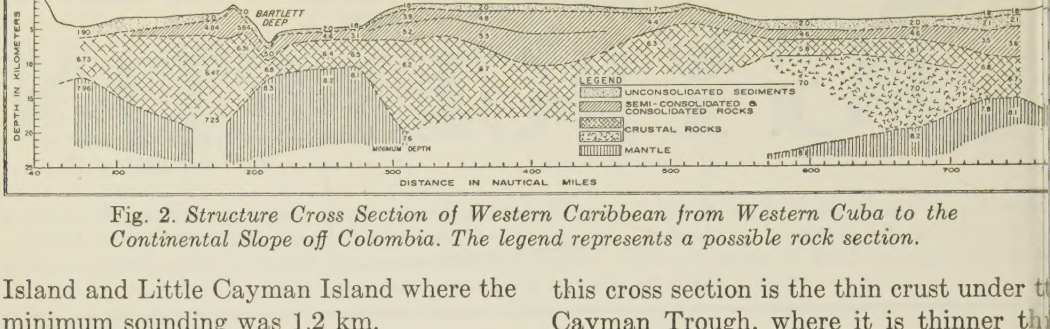


Fig. 2. *Structure Cross Section of Western Caribbean from Western Cuba to the Continental Slope off Colombia. The legend represents a possible rock section.*

Island and Little Cayman Island where the minimum sounding was 1.2 km.

Structure: The structure along the cross section is widely variable, as might be expected in an area of such varied physiography, including broad basins, prominent ridges, and a deep-sea trench. In general, there is good correlation between topography and crustal thickness: the crust is thin under the Cayman Trough, of intermediate thickness under the basins, and thick under the ridges. An entire crustal section, reaching to the base of the crust, was measured only in the Yucatan Basin, the Cayman Trough, and the southern part of the Colombian Basin. The depth to the mantle, the layer beneath the crust, is 10–11 km beneath the Cayman Trough and 14–15 km beneath the basins. The mantle depth under the ridges, as obtained by extrapolation and computations based on minimum possible depths for known seismic-wave velocities, is 20–25 km.

The seismic-wave velocities in the major crustal layer range from 6 to 7 km/sec, and in some places, the velocity apparently increases with depth in the layer. In the material overlying the main crustal layer, the velocity varies widely; hence, a clear division between the crust and the overlying material cannot always be drawn. The upper part of the section consists of sediment layers, some unconsolidated and others probably somewhat compacted or metamorphosed. The material above the main crustal layer is thickest on the Nicaraguan Rise, intermediate in thickness in the basins, and thinnest in the Cayman Trough.

The most prominent structural feature in this cross section is the thin crust under t Cayman Trough, where it is thinner th the average oceanic crustal layer (4–6 km It is also notable that the high-veloci crustal rocks are relatively thin in t Yucatan Basin and in the southern part the Colombian Basin, the thickness in the places being about the same as the avera for ocean basins. These areas of thin cru tal rocks are particularly prominent b cause of their proximity to the very thi crustal sections beneath Cuba, the ridge and the South American continent.

In the middle of the Colombian Bas the crustal rocks are at least twice as thi as the average oceanic crust, even thou the water depth is only about 1 km le than average ocean depth. A similar cond tion exists in the Venezuelan Basin, whe the crust was also found to be unusual thick everywhere except in the southe and central parts. Measurements in t areas where the thick crust was fou showed that the velocity increases dow ward in the crust. This suggests that the a erage density of much of the crustal lay in these areas is higher than that usual assumed for the oceanic crust; hence, t thick crust may be reconciled with the mo erately deep basin.

Conclusions

Most geologists and geophysicists fam iar with the Caribbean area agree that it in a state of long-range change. It is n certain, however, whether it is rising or su siding. Structure resembling an ocean bas and structure resembling a continental ma are both found along this cross secti

hin 80 mi of each other. The oceanic icture is represented by the Cayman ugh, the continental structure by the araguan Rise.

The structure under the Cayman Trough been well determined with regard to h depth to the mantle and to the seismic-wave velocities in the crust and mantle. The depth to the mantle under the Nicaraguan Rise has not been measured, but, on the basis of minimum depth calculations and extrapolation, it was estimated to be 20–25 km, or possibly deeper. This is almost within the range of continental structure.

Van Allen Radiation Belt

The following report is based in large t on material provided by James A. Van en and Louis A. Frank of the State Uni-sity of Iowa.

Regions of intense radiation surrounding earth in space were first discovered by Allen and his colleagues at the State versity of Iowa through analysis of ger-counter data telemetered to earth by llites 1958 Alpha and 1958 Gamma (Ex-ers I and III), as described in *Bulletin 13*. Special instrumentation in 1958 ilon (Explorer IV) extended knowledge of the nature of the radiation and its distribution (see *Bulletin No. 15*).

Both Pioneer I and Pioneer III, the first probes to travel many earth radii into space, traversed the Van Allen radiation belt and returned through it to burn up in the earth's atmosphere (*Bulletins 18 and 20*). Pioneer III, in particular, obtained important data. This report describes present knowledge of the radiation region, with emphasis on data recorded by Pioneer III.

Working closely with Van Allen at SUI in the design of the radiation experiment

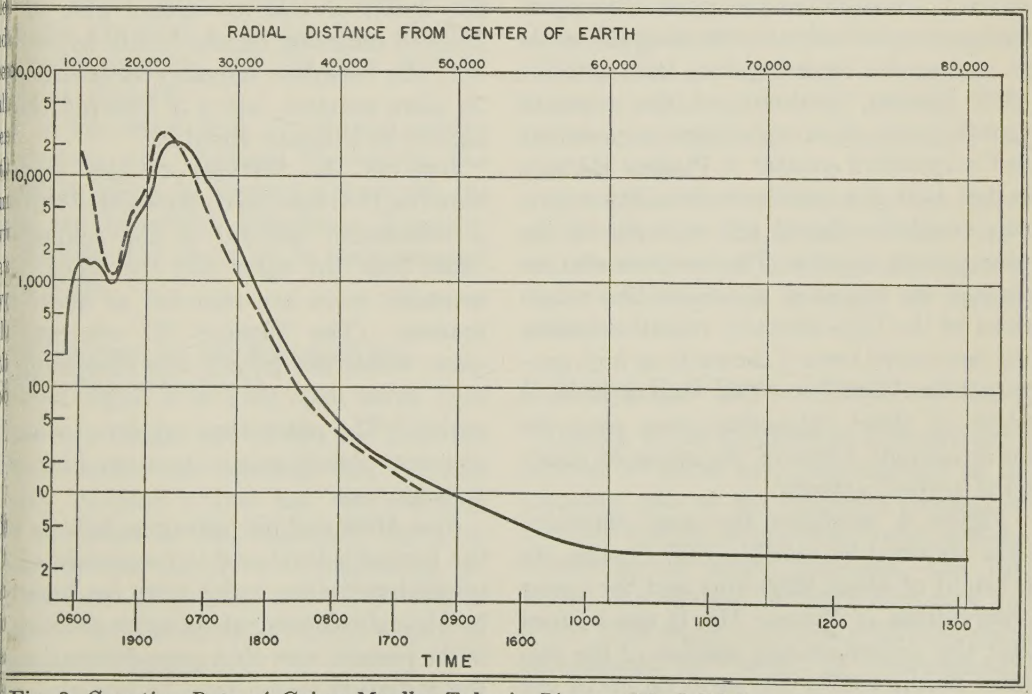


Fig. 3. *Counting Rate of Geiger-Mueller Tube in Pioneer III. Solid line represents outgoing leg, dashed line return leg. Distances in km.*

and in the interpretation of results were Carl E. McIlwain and George H. Ludwig. Dan Schneiderman of the Jet Propulsion Laboratory, California Institute of Technology, supervised the engineering of the Pioneer III payload. Partial support for the SUI portion of the Pioneer III experiment and for data analysis was provided by sub-contract with JPL.

The Radiation Region

Excellent telemetry afforded continuous radiation observations to a radial distance of 107,400 km from the earth's center on the outgoing leg of the Pioneer III flight, and from 60,000 to 9400 km on the incoming leg. Figure 3 shows the true counting rate of the standard Geiger-Mueller tube carried by the probe. The data obtained by a second counter, specially designed as an "ambiguity resolver" for the first instrument, was consistent with that of the first throughout.

The counting-rate data show the existence of two distinct, widely separated, high-intensity zones within the region of trapped, corpuscular radiation surrounding the earth. In earlier studies, using data from satellite 1958 Epsilon, contours of the constant counting rate of an instrument very similar to the standard counter in Pioneer III suggested that the maximum-intensity region was doughnut-shaped and centered on the geomagnetic equator. The contours also indicated the existence of tongue-like extensions of the high-intensity radiation reaching downward toward the earth at high geomagnetic latitudes. The higher-latitude edges of these extensions were near the lower-latitude edges of the zones of maximum auroral activity.

Figure 4 combines the very extensive data obtained by satellite 1958 Epsilon (to a height of about 2200 km) and the newer observations of Pioneer III. It can be seen that the innermost and smaller of the two zones occurs within one earth radius of the surface and encircles the earth within the

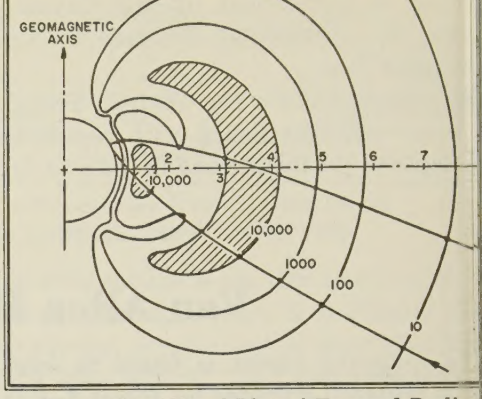


Fig. 4. *Meridional Plot of Trapped-Radiation Region. Distances given in earth radii; contours represent intensity in counts/sec.*

tropical and subtropical zones. A high 16,700 counts/sec was recorded in this z on the return leg of the Pioneer III fli The outermost zone, extending roug from two to three earth radii from the face and arcing along the lines of geom netic force to points above the polar regi had a peak of 25,600 counts/sec. Much the detail of this meridional plot of trapped radiation regions is still hypothe cal; the complete intensity-structure r be more complex, but it is believed tha cannot be basically simpler.

Because the features of the diagr based on 1958 Epsilon data persisted thro a two-month interval in the summer 1958, both the outer and the inner hi intensity zones are regarded as quasi-p manent. (The Pioneer III observati alone would not permit this conclusion they cover only part of a single two-period.) The outer zone appears to be one more closely related to usual, high-l tude auroras.

Van Allen and his colleagues believe the intensity-level and the structure of trapped-radiation region may be found be strongly dependent on solar activity is the present view that gross fluctuation the radiation region may be expected the eleven-year solar cycle. In detail, h

ver, the intensity structure may fluctuate n a much shorter time scale.

Although the Pioneer III observations ıpply no detailed information on the pene- ·ability characteristies of the radiation, 958 Epsilon data have already shown that t high altitudes near the geomagnetic quator the trapped radiation is of different haracter and is in general more penetrat- ıg than that in high latitudes. This fact, ombined with the intensity structure pic- ıre obtained from Figure 4 encourages the onjecture that the two zones may originate ı different ways. The outer zone may have s origin in solar plasma, and the inner one in cosmic-ray-albedo decay products, s suggested independently by S. N. Ver- ov, S. F. Singer, P. B. Kellogg, and by N. . Christofilos.

Another possible explanation for exist- nce of two high-intensity zones may be a elective radial diffusion of the trapped adiation within the earth's inhomogeneous ıagnetic field. This suggestion has been ad- anced by T. Gold. Such diffusion would epend upon the magnetic rigidities of the ırticles or upon a combination of their ıagnetic rigidities and the sign of their lectrical charges.

It is important that the energy spectra f protons and electrons throughout the rapping region be learned. Of special in- erest are the spectral differences, if any ex- st, between the radiation in the inner and uter zones.

adial Extent of the Effect of the arth's Magnetic Field

Between 27,000 and 37,000 km from the arth's center, the counting rate declines teeply. Beyond 37,000 km, the counting ate continues to fall smoothly, but pro- ressively less steeply with increasing ra- ial distance. Beyond about 64,000 km, or 0 earth radii, the rate of decline is greatly ecreased (Fig. 3).

Although no abrupt cut-off exists, it eems reasonable to consider 10 earth radii as approximately the outer limit of the trapped radiation. At this distance, its intensity is substantially less than the intensity of interplanetary cosmic rays.

Interplanetary Cosmic Ray Intensity

The counting rate decreases very gradually beyond 10 earth radii. It seems to have reached an asymptotic value of 2.25 counts/sec at 17 earth radii, the farthest limit of the observations. The observed dependence of counting rate on radial distance makes it likely that the contribution of a residue of trapped radiation is negligible at a distance of 17 earth radii.

The denser portion of the earth's atmosphere subtends a solid angle of only 10^{-3} of a sphere at the probe's position when 17 earth radii out. Hence, the high-energy escape albedo of the earth is negligible at this distance, as is the atmosphere's capacity for scattering and absorption of high-energy, primary cosmic rays.

At this radius, the expected Stoermer cut-off—the minimum energy that particles must have to penetrate the geomagnetic field—is 0.03×10^9 volts magnetic rigidity; for protons, this corresponds to kinetic energies of 5×10^5 electron volts, for electrons, to kinetic energies of 3×10^7 electron volts.

From the observed counting rate at 17 earth radii, $J_0 = 3.6 \pm 0.8$ particles /cm^2/ sec, where J_0 is the interplanetary value of the omni-directional intensity of charged particles.

Counting Rate Beyond Ten Earth Radii

During about 12 hours of measurements beyond 10 earth radii, fluctuations in the counting rate of the standard counter remained within statistical expectations. Moreover, at lesser distances, the rate varied remarkably smoothly with time and space. This seems to indicate that the probe encountered no "blobs" of interplanetary plasma during this interval or that the radiation in any such blobs it may have met

was not sufficiently energetic to penetrate the Geiger-Mueller tube walls.

The solar-terrestrial situation prevailing during the Pioneer III flight has not yet been critically assessed, but a preliminary report from the High Altitude Observatory at Climax, Colorado, indicates mild to moderate solar activity.

Measurements of the Pacific Equatorial Countercurrent

The following material was supplied by John A. Knauss and Robert Pepin of the Scripps Institution of Oceanography, La Jolla, California.

New measurements made during the IGY more than triple the earlier estimates of total eastward transport of water in the Equatorial Pacific. The revision is based on measurements of (i) the Cromwell Current, which flows eastward beneath and counter to the South Equatorial Current (see *Bulletin No. 16*), and, more recently, of (ii) the Pacific Equatorial Countercurrent. The latter flows just south of the westward-flowing Pacific North Equatorial Current, but in an easterly direction.

Prior to the IGY, the Pacific Equatorial Countercurrent was pictured as relatively shallow, with velocity and flow falling off almost to zero at a depth of about 230 meters. This concept was arrived at through calculations based on temperature, salinity, and other measurements made by H. V. Sverdrup.

Direct current observations made on the Doldrums Expedition, third of three IGY oceanographic cruises by the Scripps Institution of Oceanography, modify this picture. It remains true that the highest velocities in the Pacific Equatorial Countercurrent occur in the top 150 m, and that the peak velocity is found at about 100 m, just above the thermocline region, where water temperature falls rapidly (see Fig. 5).

The expedition found, however, that the countercurrent does not vanish beneath the thermocline, but continues to flow eastward at speeds of approximately 8–11 mi/day, and because it widens to 250–300 km, transports roughly 50% more water below the thermocline than above it.

Transport above the thermocline was in agreement with Sverdrup's estimate.

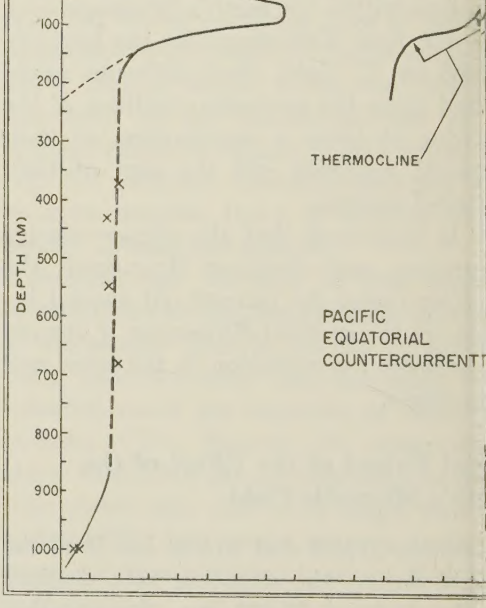


Fig. 5. *Plot of Velocity and Temperature of the Pacific Equatorial Countercurrent. Velocity profile above 200 m is composite of 12 current-meter observations made in a two-week period; below 200 m, curve is drawn from six Swallow float measurements; depth of thermocline determined from bathythermograph observations. Short-dash line represents profile expected from earlier studies.*

20–25 × $10^6 m^3$/sec, being roughly calculated by the expedition at 20 × $10^6 m^3$/sec. Transport below was calculated at 30 × $10^6 m^3$/sec. Adding these to transport calculations for the Cromwell Current (30 × $10^6 m^3$/sec) approximately triples previous estimates of the total volume of water transported eastward in the Equatorial Pacific.

The direct measurements of the Pacific Equatorial Countercurrent were made at about its center, at 7°52′N, 107°30′W. As with the Cromwell Current, observations of the top 200 m were made by suspending a propeller-type current meter from a drifting ship. The apparent current velocity at different depths was obtained from the flow of water past the meter; at the same time, radar observations were made of the ship's drift from a fixed reference point, a taut-wire buoy anchored in 2200 fathoms. Below 200 m, measurements were made by electronic tracking of the drift of submerged, neutrally-buoyant Swallow floats.

Antarctic Notes

Ornithological Studies

Much information on the habits and movements of the South Polar skua, most southerly of all birds, was obtained during IGY, Carl Eklund reported at an IGY Symposium during the 125th meeting of the American Association for the Advancement of Science.

Approximately 1500 skuas were banded at Antarctic stations, and some returns have already been received from Australia indicating migrations to that continent, and from the Belgians, Russians, and Americans on unusual skua movements within Antarctica. Argentina, Japan, New Zealand, Norway, and the United Kingdom also participated.

Penguins and skuas were dyed or sprayed with one or a combination of colors to determine the effects of color on the social behavior of the birds and to study their daily and seasonal movements. Skua chicks were dyed in the eggs. The survival rate of colored versus unmarked chicks yielded some data on the protective effects of coloration.

Prior to the IGY, six Emperor Penguin rookeries had been discovered in the Antarctic and another was suspected. The total known population of these rookeries was less than 40,000 birds. Eight additional rookeries were discovered during the IGY, and the total known Emperor Pengiun population is now estimated at more than 135,000. The largest Emperor Penguin nesting area yet found is located at 73°S, 169°E, about 250 mi north of McMurdo Sound. This rookery, discovered from a helicopter in December 1958 by Captain John Cadwalader, United States Navy, and John Dearborn, biologist, contained an estimated 50,000 birds.

The Cape Crozier rookery, first visited in 1902 by Edward Wilson of the British National Antarctic Expedition, was revisited by New Zealand scientists in September 1957. It had shifted somewhat from its original position on the sea ice and its population had increased to about 1000 adult birds, roughly five times the number estimated during the earlier visit.

Lady Newnes Ice Shelf

The disappearance of over 1000 square miles of Lady Newnes Ice Shelf, south of the joint US-New Zealand Hallett Station, has been reported by US Navy personnel supporting IGY scientific activities in the area. An ice area ten times that of the District of Columbia and 300 ft thick has disintegrated since the last charting in 1912.

Ancient Rocks

What may be the first radioactive age determination of a rock from Antarctica is reported by S. S. Goldich, A. O. Nier, and A. L. Washburn (*Transactions, American Geophysical Union,* October 1958). Paragneiss bedrock from Gneiss Point, on the west side of McMurdo Sound, was dated at 520 million years by analysis of the ratio of the A^{40} to the K^{40} isotope in biotite separated from the gneiss. (Paragneiss is a gneiss—a coarse-grained, banded metamorphic rock—derived from sedimentary rock.) The sample was collected by R. P. Goldthwait and A. L. Washburn during a short geological reconnaissance trip in December 1957.

Gneiss Point is part of the East Antarctica Precambrian shield (see *Bulletin No. 19*). It is situated on the great fault zone believed to extend from McMurdo Sound to the Weddell Sea, separating Antarctica into two distinct regions structurally. Because of Gneiss Point's location on the fault zone and its close proximity to the volcanic islands of the Ross Sea, geologic interpretation of the 520-million-year age of the rocks at Gneiss Point must be cautious.

The ancient dating of these rocks supports the Precambrian age assigned to the East Antarctic shield. Moreover, if the Gneiss Point rocks have not been affected by geologic events subsequent to the formation of the paragneiss, the metamorphic rocks may indicate a period of orogeny, or mountain building, at the close of the Precambrian, about 510 million years ago, or in Cambrian time (430-510 million years ago). This theory is given some support by A^{40}/K^{40} dates of 490 million years for biotite from gneiss at Rio de Janeiro, Brazil, and of 530 million years for granite at Cape Town, South Africa.

Expedition to "Pole of Inaccessibility"

The USSR-IGY Participating Committee reports that an expedition from Mirny Station reached the "pole of relative ina cessibility" in mid-December and estal lished a temporary station for scientific ob servations. Located at 82°06′S, 59°00′E this farthest-inland area of Antarctica 3710 m above sea level.

Seismic soundings made every 30–100 k indicate considerable irregularity of th land surface beneath the ice between th USSR Sovietskaya IGY Station (78°24′S 87°35′E) and the pole of inaccessibilit The sub-ice surface appears to be above se level virtually everywhere along the rout

At 81°05′S, 65°E, the land surface be neath the ice was tentatively reported to b 3000 m (almost 10,000 ft) above sea leve At the pole of inaccessibility itself the ic bottom was about 800 m above sea leve indicating a total ice thickness there o 2910 m, or about 9545 ft. Near Pioneer skaya, one sounding showed the ice to ex tend to a depth of 1500 m below sea leve The snow surface at 80°S, 77°E was foun to be 4070 m, or 13,185 ft, above sea level

Byrd Station Traverse

The 1958-59 oversnow traverse part from the US-IGY Byrd Station reporte recently the discovery in the Horlick Moun tains of sandstone-shale coal beds contain ing leaf fossils and petrified tree remain 12 ft long. The coal beds varied in thickness from a few inches to a few feet and con tinued in alternate layers with the sand stone and shale for nearly 2000 ft of sec tion. Fossil bivalve shells were found i basal sands.

The Horlick Mountains extend eastwar from the southeast end of the Ross Ice Shel for hundreds of miles. The traverse part found the Horlicks to consist of sedimen tary rocks overlying granites, resemblin the mountains of Victoria Land. Member of the party climbed 4000 ft of sediment whose strike was generally east-west, paral lel to the trend of the mountains; the roc layers dipped about 5° to the south.

Oxygen Isotope Studies

The following report is based upon material furnished by Samuel Epstein and Robert P. Sharp, Division of Geological Sciences, California Institute of Technology.

Laboratory determinations of the variations in the ratio of the O^{18} to the O^{16} isotope in glacial ice are of considerable value in ascertaining the relative temperature of the ice when it first fell as snow. Such analyses make it possible to distinguish the pattern of seasons where the annual ice layering has become obscured or where seasonal distinction is otherwise difficult.

In the Antarctic, oxygen-isotope ratios provide a means for identifying annual accumulation layers where other methods fail. Identification of these layers is essential for evaluating the accumulation rate of Antarctic ice bodies and their immediate past history. This, in turn, is related to fundamental problems such as world climatic changes and fluctuations of sea level. Study of the O^{18}/O^{16} ratio in ice cores from deep drill holes at Byrd and Little America IGY Stations should provide a record of relative climatic changes during the past 500 to 1000 years.

The analysis of O^{18}/O^{16} ratios in ice samples, collected at various locations in the Antarctic, Greenland, and from mountain glaciers in the continental United States and in Alaska, is being performed at the California Institute of Technology under the direction of Samuel Epstein.

Theoretical Considerations

From measurements of the isotopic composition of ocean waters, rain, snow, and ice it is possible to postulate a simple model to explain the gross variations in the H_2O^{18}/H_2O^{16} ratio in the meteorological cycle. Such variations result from the differences in vapor pressure between these isotopic molecules of water.

The behavior of this water is considered to be much like that of liquid and vapor in a multi-stage distillation column with reflux. In such a column, the vapor rising from the boiler passes to cooler and cooler parts of the column, and as condensation occurs its content of the less volatile H_2O^{18} molecule is progressively depleted. As a result, the O^{18}/O^{16} ratio in the water becomes lower as the temperature of condensation decreases. Similarly, the O^{18}/O^{16} ratio of natural precipitation is closely related to temperature. The higher the latitude and the altitude, the less H_2O^{18} the precipitate should have. Furthermore, in any one locality, winter precipitation has a lower O^{18}/O^{16} ratio than summer precipitation.

The effect of temperature on the O^{18}/O^{16} ratio of rain and snow has been confirmed many times. Tropical rain contains the highest concentration of H_2O^{18}, snow the lowest. The precipitation in cooler, higher-altitude areas has less H_2O^{18} than that of lower-level areas. Because of this temperature effect, the O^{18}/O^{16} ratios in accumulated snows of permanent ice regions should reflect the altitude of accumulation and the seasonal variations in temperature. Thus, the variation of the O^{18}/O^{16} ratio in natural precipitation is useful in the study of many problems in glaciology.

Study of systematic seasonal variations aids in determination of rates of snow accumulation, in dating of snows, and in correlation of different stratigraphic layers. In addition, if variations in the O^{18}/O^{16} ratio of snows in the accumulation areas are known, it is possible to identify patterns of flow in the ice tongue and to measure subsequent alterations affecting the O^{18}/O^{16} ratio of ice.

Analysis Program

The task of analyzing snow and ice samples collected during IGY got underway slowly, partly because the samples began reaching the laboratory only recently and partly because it was desirable to have on hand as representative a selection of

samples as possible before attempting to analyze any particular set of them. Preliminary results are available from oxygen-isotope analysis of ice samples from Greenland, from the Blue Glacier, in Olympic National Park, Washington State, and from the IGY South Pole Station. Other Antarctic samples are under study.

In the included figures and table, δ represents the O^{18}/O^{16} ratio of the sample relative to the mean O^{18}/O^{16} ratio of ocean water, according to the following formula:

$$\delta = \left[\frac{O^{18}/O^{16} \text{ ratio of sample}}{\text{mean } O^{18}/O^{16} \text{ ratio of ocean water}} - 1 \right] 1000$$

Since $\delta = 0$ is the mean ratio for ocean water, negative values represent lower ratios and positive values higher ratios than that of ocean water.

Greenland: Through the cooperation of Carl Benson of the US Army Snow, Ice and Permafrost Research Establishment, a series of firn samples from depths of several meters were collected in pits at a number of localities on the Greenland icecap. (Firn is compact, granular snow that has lasted through at least one summer.) Samples of ice were also supplied from depths of about 100 and 300 m in one of the deep bore holes drilled by the SIPRE team.

Figure 6 shows the seasonal variation in O^{18}/O^{16} ratio of snow with depth for two collection sites in northern Greenland, 360 km apart and at elevations of about 2440 and 3060 m. The summer snows have the highest O^{18}/O^{16} values relative to the mean values in ocean water, and the winter snows have the lowest (i.e., more negative) values. (In some cases, the variations are as much as 200 times the precision of measurement.)

The differences in amplitude of the O^{18}/O^{16} ratio variations shown in Figure 6 are worth noting. In spite of the great distance separating the two sites, there is surprisingly good correlation of these amplitudes for the same year of accumulation. For these sites, the summer and winter accumulation layers were identified independently

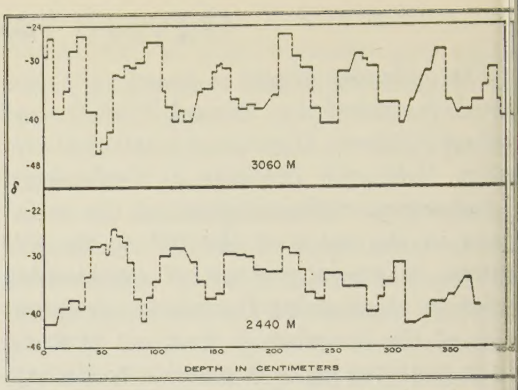


Fig. 6. *Seasonal Variation of the O^{18}/O^{16} ratio, δ, with Depth at Two Sites in Greenland. The sites, at heights of 10,000 and 8,000 ft (3060 and 2440 m) are 360 km apart.*

by glaciological evidence prior to the isotope study. The results of the two methods compare almost perfectly.

Figure 7 shows the seasonal variation at depths of about 100 and 300 m in the SIPRE deep bore hole in Greenland. Even at these depths, where most of the grain characteristics of the ice have been obliterated, the seasonal variations in the O^{18}/O^{16} ratio are still preserved. Thus, where other criteria failed, it was possible to use isotope data to determine rates of accumulation for ice at least 800 years old.

TABLE 1
Snow and Firn Samples from South Pole IGY Station

	Depth (cm)	δ
SP-101 Shallow Pit #2	40–45	−52.35
SP-102 " " "	80–85	−52.82
SP-103 " " "	115–120	−52.37
SP-30 Main Pit	195–200	−49.89
SP-29 " "	245–250	−46.50
SP-28 " "	280–285	−47.29
SP-27 " "	275–280	−46.87
SP-26 " "	320–325	−44.42
SP-25 " "	345–350	−47.51
SP-24 " "	382–387	−50.86
SP-23 " "	420–425	−47.64
SP-22 " "	465–470	−48.43
SP-21 " "	510–515	−49.89
SP- 5 " "	855–860	−50.82
SP-15 " "	1265–1270	−47.70
SP- 9 Deep Pit #1	1071–1076	−47.70

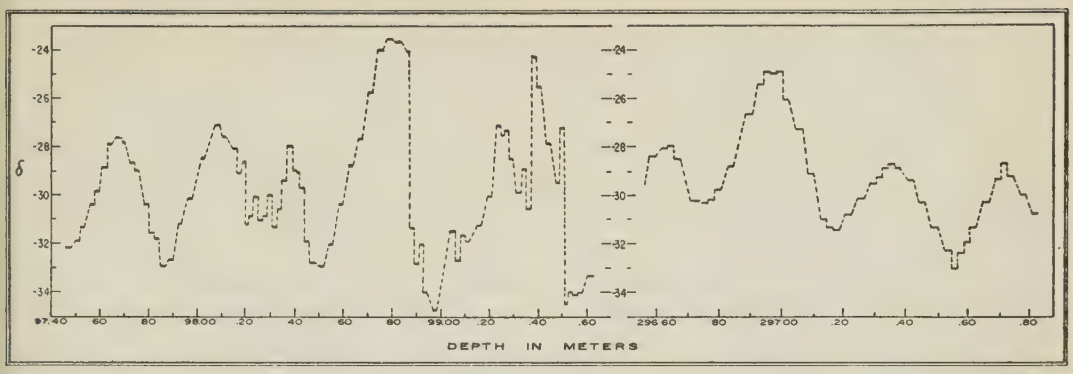


Fig. 7. *Seasonal Variations in O^{18}/O^{16} Ratios at Depths of about 100 and 300 m in the SIPRE deep bore hole in Greenland.*

IGY South Pole Station: The Greenland analyses, now nearly completed, demonstrate the validity of certain basic relations in the isotope ratio of ice and snow that can be applied to samples from the Antarctic. Table 1 shows some of the data for the South Pole station. Unfortunately, not enough samples were collected from a single accumulation layer to determine the regularity of the seasonal variation. On the other hand, large variations in the O^{18}/O^{16} values relative to the mean sea-water value exist, and the regularity and amplitude of this variation can be tested by further samplings. The O^{18}/O^{16} ratios in the South Pole samples are the lowest yet measured, confirming the basic premise regarding temperature control.

Blue Glacier: On Blue Glacier (see *Bulletin No. 11*), samples of snow, firn, and ice were collected for O^{18}/O^{16} ratio analysis at sites ranging from the glacier's terminus to well up in the firn basins. E. R. LaChapelle and colleagues, of the University of Washington, collected specimens of snow as it fell during the winter on the upper part of the glacier. Epstein, Sharp, and their associates, from Caltech, made similar collections on the remainder of the ice stream. These same layers were sampled again months later. When analyzed, the later samples will indicate the changes in O^{18}/O^{16} ratio, if any, that occurred during the processes of firnification in the intervening interval.

Samples were taken along two longitudinal profiles, one on each of the two principal ice streams, from the firn limit almost to the terminus. Several transverse profiles across the glacier below the firn limit were sampled in detail. Additional sites were sampled locally to test special relations, including a core hole for determining possible changes of O^{18}/O^{16} ratios with depth. In addition, samples of firn taken from three separate pits at different elevations will afford a means of checking and evaluating the effect of altitude of accumulation on O^{18}/O^{16} ratios.

Only a few of the Blue Glacier samples have been analyzed as yet, but the data thus far available permit the following tentative conclusions:

1) The snow and firn feeding the Blue Glacier are relatively rich in O^{18}, as would be expected from the modest winter temperatures, the maritime nature of the environment, and the relatively short period of precipitation of the air masses involved prior to their arrival over the Olympic peninsula.

2) It appears that winter snow may be enriched in O^{18} during the process of firnification, as might be expected if the refreezing of melt water is the principal process involved. However, the data are as yet too few to be reliable, and they are not completely consistent.

3) Analyses made to date support the idea that masses of *firneis* (fine-grained, equigranular ice resembling coarse-grained thawed firn) in the Blue Glacier represent bodies of snow incorporated into the glacier, probably as crevasse fillings. In most instances, the *firneis* contains more O^{18} than the surrounding, coarsely crystalline glacier ice, suggesting that the *firneis* originated at a lower elevation. The analyses are still too few to permit the conclusion that all *firneis* is of this origin.

4) Closely associated masses of bubbly blue ice and clear blue ice have consistent differences in O^{18}/O^{16} ratios. These particular differences suggest that the processes producing the clear blue ice have either removed O^{18} or added O^{16}. This may mean that the clear blue ice is formed by some mechanism of slow recrystallization rather than by refreezing of melt water that has permeated it. The latter process would in general produce higher rather than lower O^{18}/O^{16}.

Structure and Circulation of the Stratosphere

The following report is based upon a paper given at the IGY Symposium at the Meeting of the American Association for the Advancement of Science, Washington, D. C., December 29-30, 1958, by Sidney Teweles, US Weather Bureau.

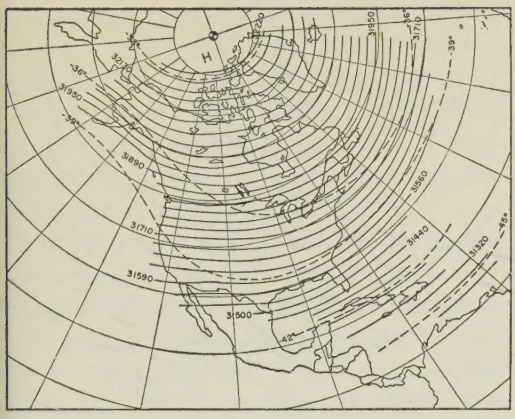
With the aid of the large quantity of high-altitude data obtained during the IGY, meteorologists are now beginning a greatly intensified program of research into the exact nature of the stratosphere. (The stratosphere is here taken to be the atmospheric layer extending downward from the 35-km level to the tropopause, which forms the upper limit of the troposphere, approximately 10 km high at the poles and 18 km high at the equator.)

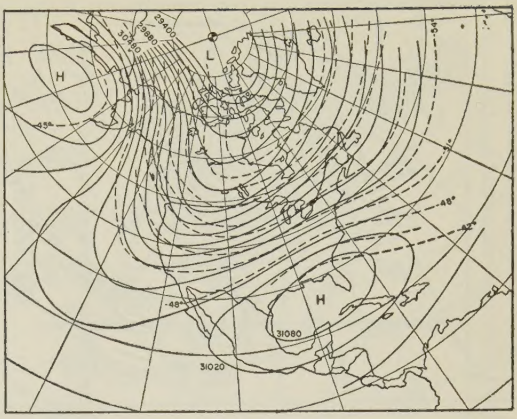
Analysis of IGY data will permit a much more accurate description of the temperatures, flow, and density of the stratosphere. This information is required, not only as a basis for further theoretical investigations, but also for application to immediate problems arising from current and anticipated traffic of aircraft, rockets, missiles, and balloons in and through the stratosphere. Furthermore, although only about 2% of the mass of the atmosphere exists above 25 km, some meteorologists believe that processes taking place above this level, where the sun's energy is first absorbed, may be significantly linked with the major motions in the troposphere.

Outline of Program

The collection of stratospheric data during the IGY was noteworthy in several respects: the number of radiosonde stations in polar and equatorial areas was greatly increased; station networks were filled out; the number of night balloon flights into the stratosphere was greatly increased by special conditioning of balloons to withstand very low temperatures; larger balloons (800-gm capacity) carried the instruments to greater heights than ever before. By these means, sufficient synoptic data on the upper portion of the stratosphere were gained to permit analysis of horizontal temperature and flow patterns up to the 31-km level.

A large percentage of the data was evaluated and transmitted almost instantly throughout the world, so that large-scale phenomena could be studied even as they occurred. Nevertheless, the fullest results of the IGY will follow careful future studies, based upon the complete, checked data that will soon emanate from the IGY World Data Centers.





Figs. 8 (left) and 9. *10-mb Pressure Surface Over North America on July 15 and November 15, 1957, Respectively. Heights in meters (solid line); temperatures in degrees Centigrade (dashed line); contour interval, 30 m (left) and 120 m (right).*

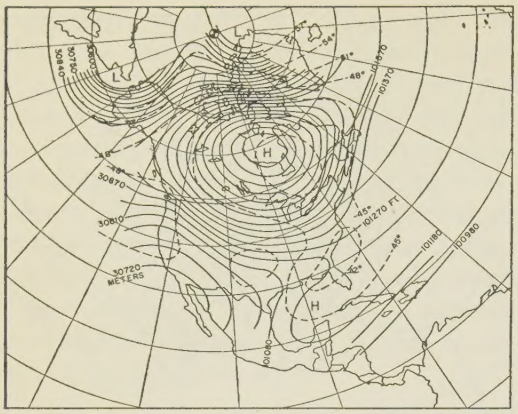
A gross division of the stratosphere into upper and lower layers and into equatorial, mid-latitude, and polar zones can already be made. To analyze the interactions between these layers and zones, and the variations between hemispheres and between seasons, is a complex task requiring the integrated efforts of many specialists throughout the world.

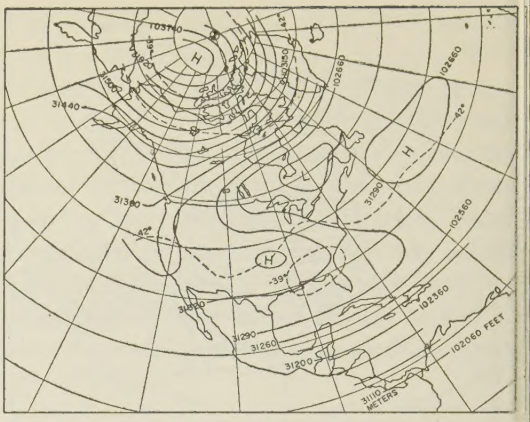
The preliminary digestion of raw IGY data in analysis centers has already been arranged and will permit many research groups to begin their studies at a more advanced stage. As a contribution to the stratospheric research effort, the US Weather Bureau has begun the production of 100-mb (16-km) and 50-mb (20-km) constant-pressure-surface charts of the Northern Hemisphere and has under consideration the analysis of 30-mb (24-km) and 10-mb (31-km) charts, pole-to-pole cross sections, and stratospheric constant-pressure charts for one or more surfaces in the Southern Hemisphere. A group of 10-mb charts prepared from IGY data are discussed below, along with some preliminary results of other IGY stratospheric studies.

Analysis of 10-mb Charts

The 10-mb charts for North America are the first to show temperature, pressure, and wind conditions near the 31-km level over such a large area. On July 15, 1957 (Fig. 8), the stratosphere at the 10-mb level above the North Pole was about 12° C warmer than over the equator, and the winds were from the east everywhere over North America. The stratosphere in the North Polar region then cooled rapidly and winds switched to a westerly direction. By November 15 (Fig. 9), the polar region had cooled by as much as 40° C and winds had accelerated to more than 100 knots in portions of the westerlies that encircled the polar regions. East winds continued to blow in the tropics.

The warm high-pressure cell over the Aleutians is apparently a frequent feature of the stratospheric circulation. This cell retreats and advances, expands and contracts. In some years, as shown by the chart for February 15, 1958 (Fig. 10), it intensifies and moves across the pole or into another portion of the stratosphere, which, like that over eastern Canada, is usually characterized by cold air and low pressure. The warming of the cold region may be very sudden and is usually accompanied by a dramatic change of stratospheric circulation. When the warming occurs early in the winter, there is time for the polar region to cool again and the westerlies to become re-established, as they did in 1958. By May 15, however, the heating of the polar regions by the returning sun produced an ex-





Figs. 10 (left) and 11. *10-mb Pressure Surface on February 15 and May 15, 1958, Respectively. Heights in meters and feet; temperatures in degrees Centigrade; contour interval 30 m.*

panding belt of east winds around the Arctic Circle (Fig. 11), and by mid-June, the east winds again dominated the stratosphere of the Northern Hemisphere.

Sudden Warming of the Stratosphere

Since the winter of 1952, when a sudden warming of the stratosphere was discovered over Berlin, there has been great curiosity about this phenomenon. Some of the early explanations, based on the assumption that the warming was a localized phenomenon, have been abandoned. It is now believed that sudden warming in the polar stratosphere is a manifestation of the fundamental energy transformations associated with major changes in the hemispheric circulation of the high levels.

A rough comparison of the year-to-year variations in the warming phenomenon since 1951 has been made by examining 10-day mean temperatures of the 50-mb surface over Alert, N.W.T., Canada, at 82°30′N. The most radical temperature changes were those beginning in January of the years 1952, 1957, and 1958. The 1957 warming, in fact, covered the entire extreme range of temperatures measured up to that time at Alert. Temperature increases occurring earlier in the cold season were smaller in range, of short duration, and were followed by another period of cooling. Temperature increases occurring near the time of the spring equinox led directly into summertime warmth.

IGY data from Drifting Station Alpha in the Arctic Ocean and from the IGY South Pole station, provide comparison between stratosphere warmings in the two polar regions. In 1957, the temperature of the Arctic stratosphere reached a peak late in the mid-winter month of January. In both 1957 and 1958 at the South Pole, the major warming was delayed until October, after the return of sunlight to the polar stratosphere. At the peak of the Antarctic springtime warming, the temperature exceeded any measured during the summer that followed. Just prior to the time of the peak temperature at either pole, very strong stratospheric winds are observed, indicating passage of the axis of the stratospheric jet stream across the pole as an accompanying phenomenon.

Perturbations in the Circulation of the Upper Stratosphere

Although the day-to-day changes in tropospheric winds, due to rapidly moving small-scale weather systems, are mirrored in the lower stratosphere, their influence decreases with altitude. In the upper stratosphere above the 50-mb level, very slowly

moving, large-scale patterns that extend halfway around the hemisphere dominate the circulation. Rapidly moving perturbations in the wind field, similar to those with which we are familiar at sea level, if they exist at all in the upper stratosphere, are apparently of small amplitude.

Wind direction graphs used to determine the periodicity of high stratospheric disturbances show little evidence of the four- to seven-day period characteristic of surface systems. Instead, a period of about fifteen days seems to dominate. Since the large-scale patterns of the troposphere, utilized in making long-range forecasts of the trajectories of storms and air-masses, are also slow-moving, the large-scale patterns of these two atmospheric layers may be interrelated. Thus, circulation changes in the stratosphere are expected to provide important clues in long-range forecasting of surface conditions. It is also anticipated that the reverse will apply, that tropospheric events may be used in making forecasts for the stratosphere—for example, in forecasting the initiation of the intense stratospheric cyclones and anticyclones that accompany sudden warming at high levels. A greatly expanded program is now being planned in this field.

Another phase of the IGY observational program—ozone measurement—gives added evidence of periodicity in the stratosphere. The total ozone in the atmosphere above Moosonee, Ontario, during November, 1958, has been compared with available 100-mb and 50-mb temperatures at that station (see Fig 12). The 100-mb temperature and total ozone rise and fall together, with a periodicity of six to nine days, corresponding to that of surface systems at this latitude. However, these changes are superimposed on a long-period trend that becomes more dominant at the 50-mb surface and above.

The close correlation between total ozone and temperatures at the 100-mb level is truly remarkable since total ozone is measured entirely by a surface instrument, the Dobson spectrophotometer. During the IGY, many of these instruments were installed in remote areas. The correlation of ozone variations with those of a host of other types of meteorological measurements may help to answer one of the major mysteries of the upper air—how and where does air pass back and forth between the troposphere and the stratosphere?

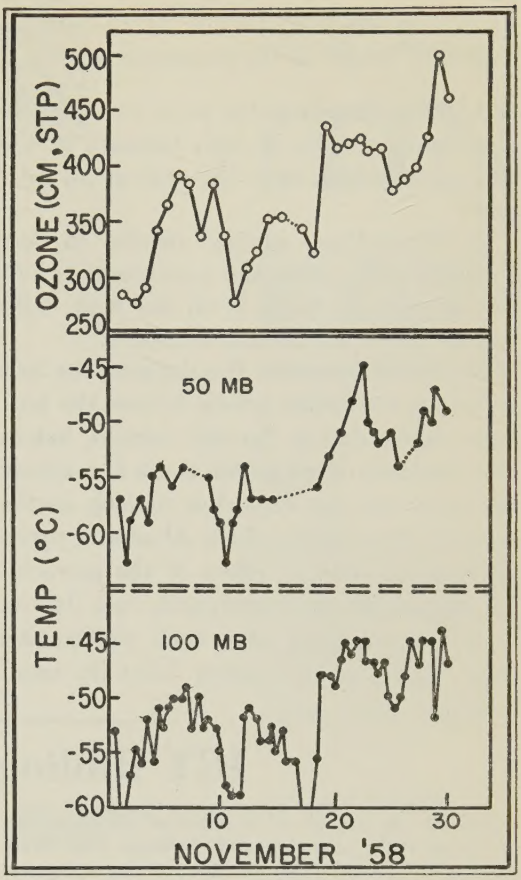


Fig. 12. *Comparison of Total Ozone (at Standard Temperature and Pressure) With Temperatures at the 50- and 100-mb Levels Over Moosonee, Ontario, During November 1958.*

Concluding Remarks

The ability of meteorologists during the IGY to obtain, at ever higher atmospheric levels, sufficient synoptic data for a full analysis of the temperature and wind fields

gives the following picture of the annual course of events in the stratosphere:

1) The warmth of the polar stratosphere in summer results in high pressure at the poles and winds from the east at all latitudes.

2) Wintertime cooling results in low pressure at the poles and a surrounding belt of very strong winds from the west, with weaker westerlies in mid-latitudes.

3) In the Southern Hemisphere, the belt of strong westerlies closely follows the latitude circles during the cold months, but in the Northern Hemisphere there is a strong tendency for the westerlies to loop northward in the vicinity of the Aleutians, probably as an indirect effect of the powerful jet stream in the troposphere over Japan.

4) One or more times each winter, this loop amplifies and moves from its usual position, causing warm air to flood acro the pole and the cold polar air to be di placed into mid-latitudes.

5) At the South Pole, stratospheric hea ing has been observed to occur only aft the sun returns in the spring and is cl maxed by a final surge of extreme heatin as the circulation around the pole revers from westerly to easterly.

6) The large scale of stratospheric m tions suggests that relationships importa to long-range forecasting will eventually b shown to exist between them and the larg scale motions of the troposphere.

7) The study of daily values of some u usual meteorological elements, measured some selected parts of the globe for the fir time, may close some of the gaps in o understanding of the complex general ci culation of the atmosphere and lead novel forecasting methods.

IGY Bibliographic Notes

This is the eighth of a series of bibliographic notes on IGY programs and findings. The references are selected from an IGY bibliography under preparation in the Science and Technology Division of the Library of Congress. (An interim bibliography prepared by the Library and published by the National Academy of Sciences, with support by the National Science Foundation, is available from the Academy for $1.00.)

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